# Operational Processing of Satellite Sea Surface Temperature Retrievals at the Naval Oceanographic Office

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## ABSTRACT

A complete overview of the national Shared Processing Program (SPP) satellite sea surface temperature (SST) retrieval product is presented. This paper summarizes the operational processing of digital Advanced Very High Resolution Radiometer (AVHRR) satellite data into a global SST retrieval product at the Naval Oceanographic Office (NAVOCEANO). Satellite SST generation is described, detailing data processing procedures, algorithms used, and quality control techniques. User interaction and data monitoring through the SPP algorithm research panel for SST is presented along with SST products and information available to users. The NAVOCEANO national SST product consists of more than 150 000 global retrievals per day and demonstrates monthly bias errors less than 0.1°C and root-mean-square difference errors less than 0.6°C relative to global drifting-buoy measurements. The product is important to and operationally utilized within thermal structure analyses, civilian and military maritime activities, and numerical weather prediction forecasts.

## 1. Introduction

Since 1981, the National Oceanic and Atmospheric Administration/National Environmental Satellite, Data and Information Service (NOAA/NESDIS) provided operational Multi-Channel Sea Surface Temperature (MCSST) retrievals (McClain et al. 1983). In June 1993, the operational processing of global MCSST retrievals was transferred from NOAA/NESDIS to the Naval Oceanographic Office (NAVOCEANO), which became the Shared Processing Program (SPP) National Core Processing Center for the production of global MCSST retrievals. SPP is an interagency sharing of satellite-derived environmental data and associated products among NOAA/NESDIS, NAVOCEANO, the Fleet Numerical Meteorology and Oceanography Center (FLENUMMETOCCEN), and the Air Force Global Weather Central (AFGWC) (Dumont et al. 1996). This transferral to NAVOCEANO marked the first successful operational processing transition between major satellite processing centers.

A key SPP initiative is to minimize Department of Defense (DOD) and NOAA economic costs through processing center cooperation and agreements to share satellite data processing capabilities. The SPP centers share data by utilizing the Domestic Communications Satellite (DOMSAT) transmission capabilities. Dumont et al. (1996) describe the present SPP center data distribution links and address future communication plans. A core processing center concept was developed to identify specific satellite products to be generated at each center and subsequent dissemination to the other processing centers. Algorithm research panels for these products have been established to regularly review, evaluate, and approve/standardize processing techniques and algorithms. The algorithm research panel for sea surface temperature (ARP/SST) provides these functions for the NAVOCEANO satellite SST product.

## 2. Processing description

NAVOCEANO's Warfighting Support Center (WSC) receives Global Area Coverage (GAC) Advanced Very High Resolution Radiometer (AVHRR)

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1b and High Resolution Infrared Radiation Sounder (HIRS) 1b digital data from NOAA/NESDIS over SPP. Approximately 14 individual orbits of data are received in near real time each day. The satellite SST product is generated at NAVOCEANO from these datasets and then transmitted to the other SPP processing centers. SST retrieval production follows the fundamental theory and validation documented by McMillin and Crosby (1984) and McClain et al. (1985), whereby differential spectral absorption in multiple infrared (IR) channels is utilized to obtain absolute SST estimates. Several modifications and improvements to this MCSST process have evolved over time and are covered in ensuing paragraphs. Since transferral to NAVOCEANO, SST processing has made the analysis of operational processing techniques accessible to the academic community and outside government agencies for suggested modifications through establishment of the ARP/SST. NAVOCEANO has also established electronic access to real-time SST algorithm information, satellite SST data, satellite–buoy SST match files, and processing event logs; extended satellite SST retrieval capability up to 80°N latitude; improved the global processing coastline database; increased the density and reliability of coastal retrievals worldwide; improved daytime cloud detection in sun-glitter regions and ice-covered areas; and improved SST retrieval density in dusk/dawn conditions.

Support of operations at NAVOCEANO and delivery of products to the fleet requires that each GAC orbit is processed within 6 h of receipt of the raw data by NOAA/NESDIS, that SST accuracy maintains a root-mean-square difference (rmsd) error of less than 0.7°C relative to global drifting-buoy SST measurements, and that global SST coverage from 70°N to 70°S latitude is provided. These requirements are necessary to provide accurate near real-time information to global and regional thermal analysis and model products described in section 3. NAVOCEANO executes its charter as the core processing center for global SST processing by surpassing these requirements for accuracy, timeliness, and coverage. NAVOCEANO has consistently produced approximately 150 000 satellite SST observations per day (Fig. 1a) and maintained a monthly rsmd of 0.5° to 0.6°C (Fig. 1b). Bias errors relative to global drifting-buoy data are also consistently less than 0.1°C (Fig. 1c). McClain (1989) and May (1993) have demonstrated that such accuracies are also relatively consistent when stratified by region. NAVOCEANO creates satellite SSTs from 80°N to 70°S latitude within 5–10 min of receipt of the GAC 1b and HIRS 1b data over SPP. An example of *NOAA-14*

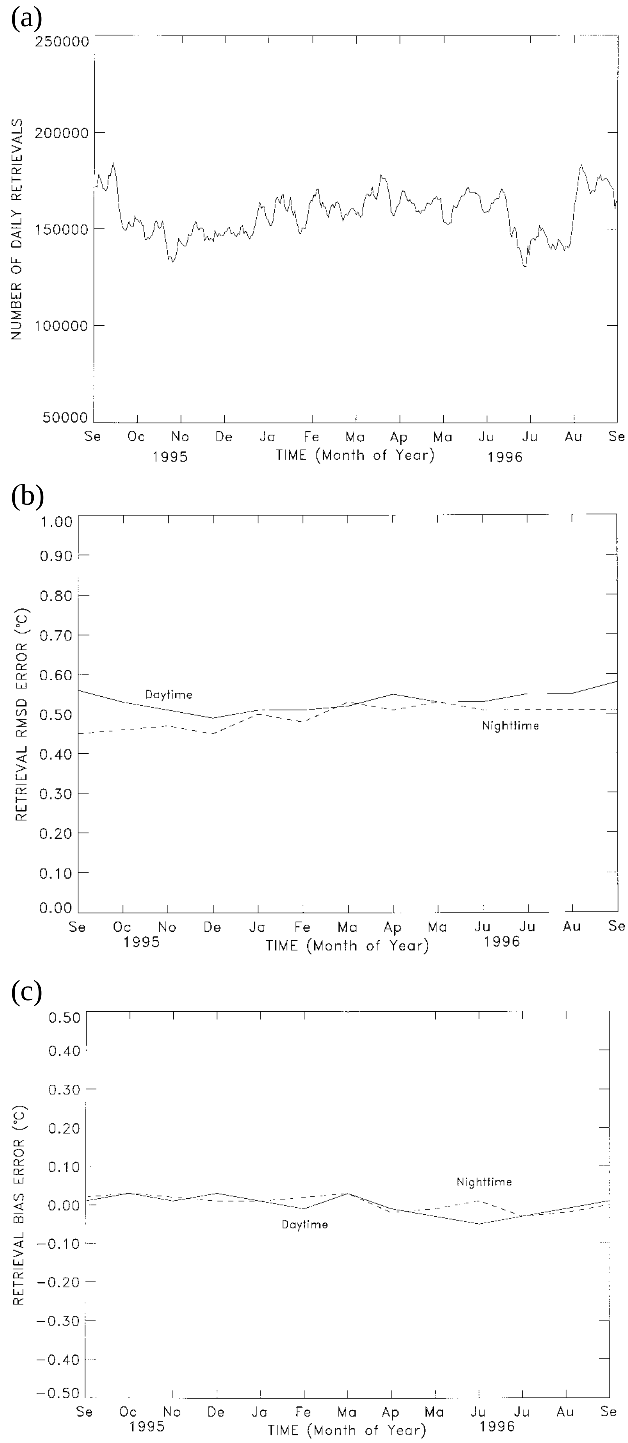


FIG. 1. For satellite SST retrievals produced at NAVOCEANO from September 1995 through September 1996: (a) daily number of satellite SST retrievals, (b) monthly root-mean-square difference, and (c) monthly mean difference relative to global buoy measurements.

global data coverage for one week is presented in Fig. 2. Orbits are sun synchronous, providing regional coverage at a fixed location about every 12 h. SSTs are calculated for orbital swath widths of approximately 2300 km. Electronic access has been established for operational processing event logs, algorithm information, retrieval coverage, satellite SST data, and product accuracy. This information is available on the World Wide Web at http://www.navo.navy.mil.

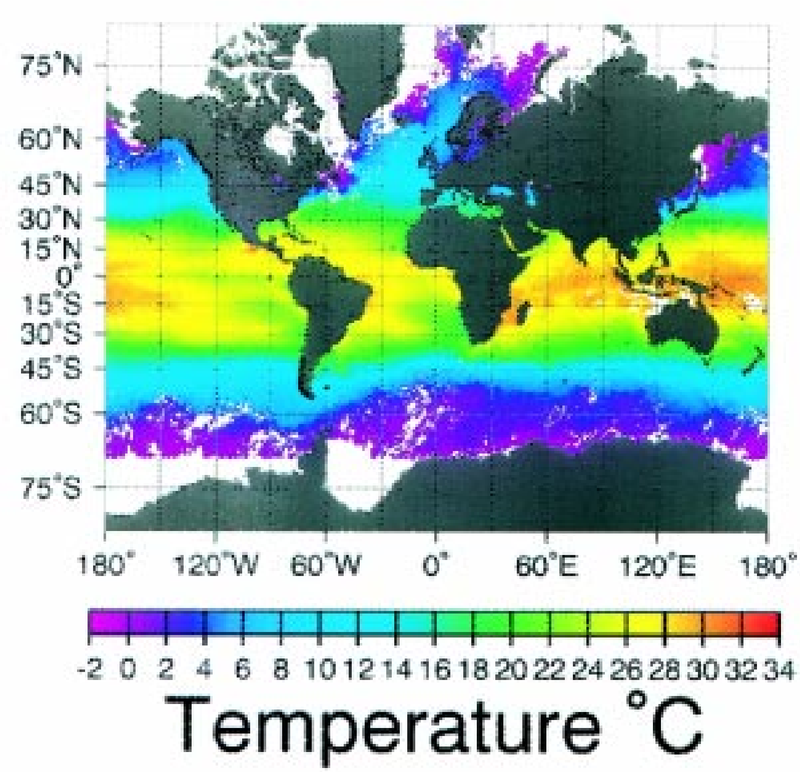


FIG. 2. Global data coverage of SST retrievals for 8 days ending on 29 January 1997.

Satellite SST retrieval processing and quality control is performed on the NAVOCEANO Satellite Processing System (SPS). Individual channel data is calibrated following the techniques described in Rao et al. (1993) and Rao and Chen (1996). AVHRR GAC 1b data records undergo extensive quality checks for scan time and frame synchronization errors and/or incorrect calibration coefficients. All satellite data must also pass numerous cloud detection tests before a satellite SST retrieval is generated. This process ensures that satellite SSTs are derived from only high quality, cloud-free pixels. Each of these steps are presently tailored to *NOAA-14* AVHRR and HIRS sensors. Although each step is appropriate for other satellites in this series, individual test-threshold values are usually modified when operational satellites change to attain the most accurate results.

NAVOCEANO SST processing utilizes visible, near-IR, and IR threshold tests; spatial coherence threshold tests; and multichannel intercomparison tests that utilize AVHRR IR and HIRS IR channels (Table 1). The cloud tests differ according to whether daytime or nighttime satellite data are available. Figure 3 presents the sequence of satellite SST processing steps. These steps are discussed in detail below.

### *a. Operational processing procedures*

#### 1) DAY/NIGHT DETERMINATION

Daytime cloud detection algorithms and a two-channel SST equation are used when the solar zenith angle is less than 75°. Nighttime cloud detection algorithms and a three-channel SST equation are used for solar zenith angles greater than 90° if AVHRR channel-2 reflectance is less than 1%. Although some daylight is still present for solar zenith angles between 75° and 90°, visible reflectance is not sufficient for effective and consistent cloud detection using present

TABLE 1. AVHRR and selected HIRS channel characteristics.

| Channel | Wavelength($\mu$m) |
|---|---|
| **AVHRR** | |
| 1 | 0.58–0.68 |
| 2 | 0.725–1.10 |
| 3 | 3.55–3.93 |
| 4 | 10.3–11.3 |
| 5 | 11.5–12.5 |
| **HIRS** | |
| 7 | 13.3 |
| 8 | 11.1 |

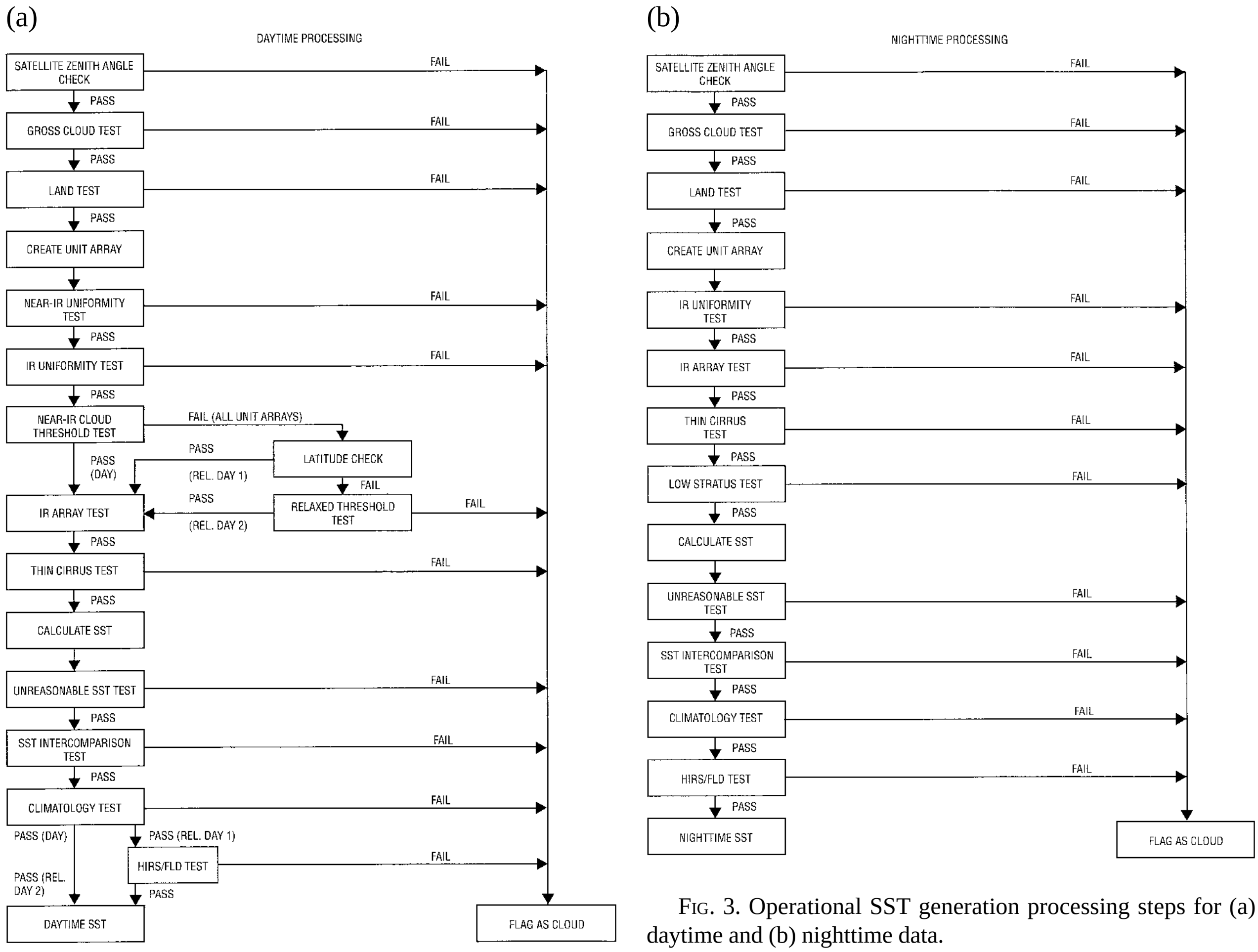


FIG. 3. Operational SST generation processing steps for (a) daytime and (b) nighttime data.

AVHRR visible and near-IR channels. For these solar zenith angles, nighttime cloud detection algorithms are used if AVHRR channel-2 reflectance is less than 1.8%; otherwise the pixels are not processed. NOAA-K AVHRR visible and near-IR channels will be more sensitive to low reflectance and may offer improved cloud detection in this solar zenith angle range.

All SST processing is performed by searching an $11 \times 11$ target of 4-km AVHRR pixels for cloud-free elements. Image pixels that pass all tests are used to produce SST retrievals from cloud-free $2 \times 2$ pixel unit array averages at a spatial resolution of 8 km. Currently, up to eight SST retrievals can be generated per $11 \times 11$ pixel target during the daytime and one retrieval per target during the nighttime. Work is in progress to significantly increase the total generated both at day and at night.

#### 2) Daytime processing

*Satellite zenith angle check.* Daytime retrievals are attempted only for satellite zenith angles less than 53°. Increased spatial distortion and atmospheric attenuation effects at higher satellite zenith angles cause significant reductions in accuracy (Llewellyn-Jones et al. 1984).

*Gross cloud test.* To pass this test, AVHRR channel-2 reflectance must be less than 18% for 10 or more of the 121 pixel elements contained within the $11 \times 11$ pixel target being processed. Channel-2 reflectance is typically less than 5% over the open ocean and very high for intensely cloudy areas. This simple test eliminates a large portion of heavily cloud-contaminated targets early in the processing.

*Land/sea test.* Each element of the target is checked against a 5-km high-resolution land/sea tag file. If determined to be over land, the pixel is not used to calculate an SST retrieval. Pixels adjacent to those found to be over land are also flagged and not used. This prevents land elements from being misclassified as sea elements due to satellite–earth location inaccuracies. Daytime retrievals are generated within approximately 8–10 km of all coastlines worldwide between 80°N and 70°S.

*Create unit array.* If the preceding $11 \times 11$ target array tests are passed, the following tests are then attempted on $2 \times 2$ unit arrays within the target array. A search algorithm is followed such that up to eight unit arrays within the target can be processed to SST. The density of SST retrievals obtained per target is predetermined according to latitude and longitude location and can be easily modified to suit regions of interest. For daytime processing, high-density regions obtain eight retrievals per target, medium-density regions five, and low-density regions one. Although some unit arrays will be flagged as cloud contaminated, the search algorithm proceeds through the target array until the desired density of SST retrievals is obtained or until unit array choices are exhausted. If at least one unit array within the target satisfies the selection rules for being cloud free and generates an SST retrieval, then the search process proceeds to the next target array. If no unit array successfully generates an SST, then the target is searched for the warmest pixel that is nearest to the target center. Unit arrays containing this pixel are then checked in a relaxed cloud-detection mode before moving on to the next target.

*Near-IR uniformity test.* Cloud-top reflectance often varies significantly over small space scales, whereas sea surface reflectance is more uniform. A spatial uniformity test following the techniques of Coakley and Bretherton (1982) and Saunders (1986) can then be used to detect cloudy pixels. All four of the AVHRR channel-2 pixels within a $2 \times 2$ unit array must be no more than three digital counts different than the other three pixels. This threshold is typical of channel-2 cloud-free fields of view.

*IR uniformity test.* Each of the four AVHRR channel-4 pixels within a $2 \times 2$ unit array must differ no more than two digital counts from the other three pixels. This threshold is typical of channel-4 cloud-free fields of view except in very high SST gradient regions. A conservative threshold is currently used since relaxation of this value occasionally allows cloud pixels to pass.

*Near-IR cloud threshold test.* Cloud detection during the daytime is most easily achieved using the bidirectional reflectance received by channel 2. Reflectance is typically very high for cloud-contaminated pixels and less than 5% for the cloud-free ocean surface. Cloud-free ocean reflectance will differ according to sun–satellite angles. Therefore, bidirectional reflectance threshold tables are empirically derived from numerous AVHRR orbits to delineate the maximum expected channel-2 cloud-free reflectance for various sun–satellite angle combinations. The table thresholds are obtained from histogram distributions of cloud-free ocean reflectance less than 6%. Cloud reflectance is typically very high unless subpixel cloudiness exists. Histogram techniques using several months of data clearly identify the cloud-free reflectance data. The table thresholds are binned according to solar zenith angle, satellite zenith angle, and relative azimuth angle. The table is constructed from channel-2 orbital datasets (1 month minimum) and then is checked and updated several months after implementation to adjust for any sun–satellite angle changes that may have occurred due to orbit drift and/or channel-calibration drift. The latter item should become more stable since NOAA/NESDIS is now updating channel-2 calibration coefficients monthly using the technique described in Rao and Chen (1996). During operational processing, AVHRR channel-2 image data is compared to the appropriate sun–satellite geometry threshold table value. The channel-2 data must be less than the table threshold value to pass this test. The data that pass proceed to the IR array test below for further daytime retrieval cloud detection testing. For medium- and high-density retrieval targets, all unit arrays within the target are checked until the required density is satisfied or until unit array options are exhausted. If at least one daytime retrieval is generated, the next target is then searched. If no retrievals are obtained, a relaxed daytime retrieval is then attempted as described immediately below. Only one relaxed daytime retrieval per target is attempted and only if no daytime retrievals were generated for that target.

*Relaxed near-IR cloud threshold test.* Specular reflectance off a cloud-free ocean surface can often exceed 10%–15% for some sun–satellite angle combinations and subsequently be rejected by the near-IR cloud threshold test. To increase the chance of obtaining retrievals under such conditions, the table thresholds are relaxed if the near-IR cloud threshold test fails for every unit array searched within a target array. First the latitude of the potential retrieval is checked. If the retrieval is located at high latitude, the threshold is increased by a factor of 1.5. This relaxation allows for some more retrievals to be produced in specular reflectance regions while also limiting possible retrievals over ice. The highest *NOAA-14* specular reflectance normally occurs at mid- to low latitudes where a relaxation of 1.5 is often not high enough. For these latitudes, the near-IR cloud threshold is ignored and cloud detection relies on the remaining daytime tests, primarily the HIRS/100-km field test described later. Passage of the relaxed near-IR cloud threshold test and the ensuing tests results in a relaxed daytime retrieval.

The daily ratio of daytime to relaxed daytime retrievals is typically 3:1.

*IR array test.* The average brightness temperature of the four AVHRR channel-4 pixels within a $2 \times 2$ unit array must be warmer than 270 K. This test primarily prevents any cold-cloud or ice temperature retrievals from being generated.

*IR channel difference test.* The difference between AVHRR channel-4 and channel-5 brightness temperatures must be less than or equal to 3.5 K to pass this test. This test helps identify thin cirrus clouds and/or partially cloud-filled views that often modify the IR channel difference significantly.

*Calculate SST.* A nonlinear sea surface temperature (NLSST) (C. Walton et al. 1997, manuscript submitted to *J. Geophys. Res.*) estimate is calculated for unit arrays that reach this point in the processing. Unit array average brightness temperature values for channel 4 and channel 5 are applied to the following equation:

$$\begin{aligned}\mathrm{NLSST}(4/5) = {} & 0.9355T_4 + 0.078T_f(T_4 - T_5) \\ & + 0.8009(T_4 - T_5)(\sec\theta - 1) - 254.0163, \quad (1)\end{aligned}$$

where $T_4$ and $T_5$ represent the channel 4 and 5 brightness temperatures in degrees K respectively, $T_f$ is an SST estimate obtained from a daily analyzed satellite SST global 100-km field (described in section 4) in degrees Celsius, $\sec(\theta)$ is the secant of the satellite zenith angle, and *NLSST*(4/5) is the SST retrieval in degrees Celsius.

*Unreasonable SST test.* The NLSST retrieval estimate calculated above must fall between −2.0°C and 35.0°C inclusive to be accepted.

*SST intercomparison test.* A separate linear MCSST estimate is made for the retrievals that survive each of the preceding cloud tests. Equation (2) represents the daytime MCSST algorithm used:

$$\begin{aligned}\mathrm{MCSST}(4/5) = {} & 1.0135T_4 + 2.2014(T_4 - T_5) \\ & + 0.7833(\mathrm{T}_4 - \mathrm{T}_5)(\sec\theta - 1) - 277.4234. \quad (2)\end{aligned}$$

If the MCSST and NLSST retrievals differ by more than 1.5 K, the retrieval is rejected. For cloud-free conditions, each equation will generate similar results, even for changes in atmospheric conditions. Under cloudy conditions, the equations will generate significantly different results depending on the cloud types sensed.

*Climatology test.* The NLSST retrieval estimate must not differ from the monthly SST climatology at that location by more than 10°C. Unit arrays that pass the near-IR cloud threshold test and subsequent tests including this one become valid daytime retrievals at this point and skip the HIRS/100-km field test below. In addition, relaxed daytime retrievals that pass the relaxed threshold check (relaxed day 2 in Fig. 3a) also skip the HIRS/100-km field test and become valid relaxed daytime retrievals. Only the unit arrays that pass the latitude check (relaxed day 1 in Fig. 3a) proceed to the HIRS/100-km field test.

*HIRS/100-km field test.* This test provides for better cloud-screening capability in relatively warm and uniform cloud scenes that occasionally go undetected by AVHRR IR channel techniques (C. Walton et al. 1997, manuscript submitted to *J. Geophys. Res.*). HIRS channel 7 (13.3 $\mu$m) and channel 8 (11.1 $\mu$m) are used to determine the effective difference in radiance contribution from the atmosphere between 900 mb (channel 7) and the surface (channel 8). This brightness temperature difference is significantly greater in a cloud-free scene than in a cloudy scene. The HIRS test utilizes the following equation:

$$\begin{aligned}\mathrm{HT} = {} & 0.059846T_f + 1.66(\sec\theta - 1) \\ & - 0.29754(H8 - H7) + 4.36, \quad (3)\end{aligned}$$

where HT represents the HIRS test output value, $T_f$ represents the local 100-km SST field value in degrees Celsius, and $H7$ and $H8$ represent the HIRS channel-7 and -8 brightness temperatures in kelvins, respectively. Further details regarding this equation are provided by C. Walton et al. (1997, manuscript submitted to *J. Geophys. Res.*). If HT exceeds the threshold of 0.5, the test fails. This threshold value requires the channel 8 minus 7 brightness temperature difference to be large, which is typical of cloud-free scenes. Since HIRS channel data is 20 km in spatial resolution, the possibility exists that some cloud-free 4-km AVHRR data elements might be falsely rejected. To remove this possibility, an SST field outlier test is also performed, requiring that the AVHRR SST retrieval agree within 2.5°C of a weighted average of the local 100-km field SST and climatology SST. Both the HIRS test and the field outlier test must be failed for an AVHRR retrieval to be rejected during this step. Unit arrays that pass either one of these tests become valid relaxed daytime SST retrievals.

3) Nighttime processing

*Satellite zenith angle check.* Nighttime retrievals are attempted only for satellite zenith angles less than 53°. As for daytime data, increased spatial distortion and atmospheric attenuation effects at higher satellite zenith angles cause significant reductions in accuracy.

*Gross cloud test.* To pass this test, AVHRR channel-4 brightness temperatures must be warmer than −5.0°C for 30 or more of the 121 pixel elements contained within the 11 × 11 pixel target being processed. Channel-4 brightness temperatures are typically warmer than this threshold for open water areas. This test eliminates a large portion of heavily cloud-contaminated and/or ice-covered areas.

*Land/sea test.* This test is identical to the land/sea test described previously in section 2a(2).

*Create unit array.* If the preceding 11 × 11 target array tests are passed, the following tests are then attempted on 2 × 2 unit arrays within the target array. A search algorithm looks for the warmest cloud-free pixel closest to the center of the target. Unit arrays containing this pixel are then checked for cloud contamination. Only one SST per target is retrieved at night. This conservative approach is a result of the fact that nighttime cloud detection techniques are limited to IR channel thermal information and are not as effective as daytime methods that also utilize near-IR channel reflectance data. Efforts to increase valid nighttime retrievals without also increasing cloud-contaminated retrievals are in progress.

*IR uniformity test.* All four of the AVHRR channel-4 pixels within a 2 × 2 unit array must differ no more than two digital counts from the other three pixels.

*IR array test.* The average brightness temperature of the four AVHRR channel-4 pixels within a 2 × 2 unit array must be warmer than 270 K.

*IR channel difference test.* This test is identical to the IR channel difference test described previously in section 2a(2).

*Low stratus test.* This test helps detect uniform low stratus clouds that often go undetected by IR uniformity tests. The emissivity of uniform low clouds differs significantly for channels 3 and channel 5 (Hunt 1973). A positive difference of channel 5 minus channel 3 brightness temperatures usually indicates cloud contamination. For cloud-free scenes, this channel brightness temperature difference is typically negative and influenced primarily by atmospheric water vapor content. Thus, the channel 5 minus 3 brightness temperature difference must be zero or negative to pass this test.

*Calculate SST.* An SST estimate is calculated for unit arrays that reach this point in the processing. Unit array average brightness temperature values for channels 3, 4, and 5 are applied to the following equation:

$$\begin{aligned}\mathrm{NLSST}(3/4/5) = {} & 0.9796T_4 + 0.032T_f(T_3 - T_5) \\ & + 1.8106(\sec\theta - 1) - 266.1146,\end{aligned} \tag{4}$$

where $T_3$ represents channel-3 brightness temperatures in kelvins and NLSST(3/4/5) is the SST retrieval in degrees Celsius. Channel 3 can only be used for SST retrievals at night because this wavelength contains reflected solar energy when the sensor "looks" toward the sun during daylight hours. The transmittance of radiant energy from the surface through the atmosphere is greater for channel 3 than for channels 4 and 5. This fact results in less atmospheric attenuation effects in channel 3 data, providing a more accurate SST retrieval when all the channels are used. Figure 1b demonstrates the improved accuracy of the three-channel nighttime algorithm relative to the two-channel daytime algorithm.

*Unreasonable SST test.* The NLSST retrieval estimate calculated above must fall between −2.0°C and 35.0°C to be accepted.

*SST intercomparison test.* An NLSST estimate of SST using channels 4 and 5 only and then an MCSST estimate using channels 3 and 4 only are calculated from Eqs. (5) and (6) below:

$$\begin{aligned}\mathrm{NLSST}(4/5) = {} & 0.9279T_4 + 0.781T_f(T_4 - T_5) \\ & + 0.7296(T_4 - T_5)(\sec\theta - 1) - 251.978,\end{aligned} \tag{5}$$

and

$$\begin{aligned}\mathrm{MCSST}(4/5) = {} & 1.0131T_3 + 0.3876(T_3 - T_4) \\ & + 2.0311(\sec\theta - 1) - 275.1899.\end{aligned} \tag{6}$$

Under cloud-free conditions, NLSST(3/4/5), NLSST(4/5), and MCSST(3/4) will generate similar answers, even for changes in atmospheric conditions. However, under cloudy conditions, atmospheric effects will generate different results, depending on the cloud types sensed and the channels used within each equation. These characteristics provide an effective mechanism for detecting clouds at night. The three equation results must agree within 2°C for the test to pass. If passed, the NLSST(3/4/5) equation is used to generate the valid nighttime retrieval.

*Climatology test.* The NLSST retrieval must not differ from the monthly climatology at that location by more than 10.0°C to be accepted.

*HIRS/100-km field test.* This test is implemented as previously described in the daytime cloud screening for relaxed daytime retrievals. Retrievals that pass this final nighttime cloud-detection test are considered valid nighttime SST retrievals and output to the SST product file.

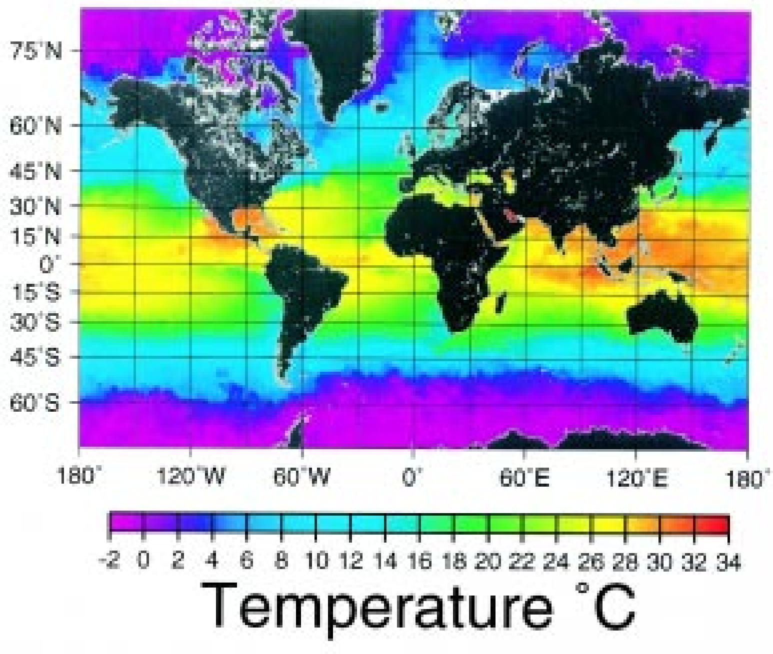


FIG. 4. Global 100-km satellite SST analysis from 23 July 1996.

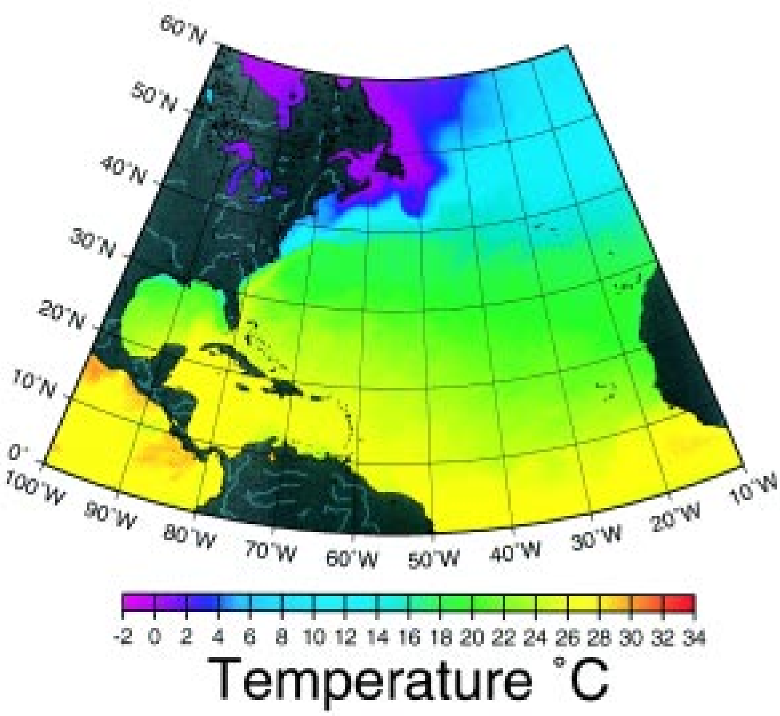


FIG. 5. North Atlantic regional 10-km satellite SST analysis from 24 February 1997.

## 3. Products to users

The NAVOCEANO WSC has provided operational satellite SSTs over SPP to FLENUMMETOCCEN and NOAA/NESDIS since June 1993. Each SPP satellite SST product comprises a single orbit of satellite SSTs. Approximately 14 orbital products are produced daily from the *NOAA-14* AVHRR. Each product file on average contains 11 000 SST observations (more than 150 000 SST observations per day). These files are formatted to SPP dissemination file specifications and contain SST values, latitude–longitude location, retrieval time, retrieval type, and other sensor information specific to each individual retrieval. The SST data within these files are available to outside users through the SPP data archive and distribution system at NOAA/NESDIS.

In June 1993, FLENUMETOCCEN began using the NAVOCEANO SST product within its Optimum Thermal Interpolation System (OTIS) (Clancy et al. 1992) thermal structure analyses. In addition, the National Centers for Environmental Prediction (NCEP) also use NAVOCEANO's SST product in their global SST analysis (Reynolds and Smith 1994). These analyses monitor the ocean thermal structure on global and regional scales in near real time. Such analyses are important to military operations and deployments, civilian maritime activities, global climate change research, and accurate numerical weather prediction forecasts such as the Navy Operational Global Atmospheric Prediction System (Hogan and Rosmond 1991).

The satellite SST product is also used internally at NAVOCEANO for oceanographic modeling efforts such as the Modular Ocean Data Assimilation System (MODAS), regional OTIS analyses, and the Shallow Water Analysis and Forecast System (SWAFS). Ocean model support consists of SST retrieval value, location, and time. NAVOCEANO also supplies the Naval Pacific Meteorology and Oceanography Center (NPMOC) and Naval European Meteorology and Oceanography Center (NEMOC) with SST products tailored for their own MODAS processing.

In addition, the NAVOCEANO WSC produces daily 100-km global (Fig. 4) and 10-km regional

(Fig. 5) satellite-only SST composites for internal quality control purposes. These products have also been used by the fleet. The Satellite Analysis Division of the WSC uses several regional 10-km SST composites to initialize its numerous ocean feature analyses. The WSC currently supports regional SST analyses for the North Atlantic, South Atlantic, northeast Pacific, northwest Pacific, southeast Pacific, southwest Pacific, and southern Indian Oceans; Mediterranean, Arabian, and Greenland–Iceland Seas.

## 4. Quality control

The ARP/SST provides scientific guidance and recommendations for SST product quality and examines retrieval algorithms for potential SST product improvement and operational implementation. Principal members of the panel are technically informed representatives from each of the SPP centers and supporting research organizations. Contributing members from the user and academic community also participate to present new research developments for operational consideration. The ARP/SST provides the research and development association necessary to maintain operational SPP product requirements. Through this panel, the navy seeks to maintain a high quality SST product through review, evaluation, and approval of satellite SST product algorithms and processes.

The satellite SST product quality is monitored on a regular basis using various datasets and techniques. The NAVOCEANO WSC produces three basic quality control databases: an 8-day satellite SST observation file, a satellite SST 100-km analyzed temperature field, and a satellite SST–buoy SST matchup database. The 8-day observation file (Fig. 2) is generated once per day with the latest eight days of satellite retrievals. This file is used to monitor global and regional coverage of the satellite SST retrievals. It is also useful in monitoring SST features and anomalies relative to climatology and the 100-km SST field.

The 100-km analyzed temperature field (Fig. 4) is used in cloud detection and SST quality control tests. This field is generated daily by objectively analyzing all retrievals collected during the past 36 h using a 1° latitude–longitude grid. Each grid-cell value is calculated by weighting the previous analysis temperature and individual satellite retrievals by distance from the gridpoint center, age of the retrieval, and strength of the previous local SST field gradient. Together the 8-day observation file and 100-km analyzed field provide SST retrieval consistency checks, which assist in quickly identifying potential processing problems.

The SST matchup database contains drifting and moored buoy SSTs and satellite SSTs that are matched within time and distance constraints of 4 h and 25 km. This file is updated each day by matching new satellite retrievals to the latest buoy SST measurements received. Global drifting buoy and Tropical Ocean and Global Atmosphere program Tropical Atmosphere Ocean array moored buoy SST measurements received through Global Telecommunication System and DOD communication lines are used to match to the satellite retrievals. Figure 6 shows the typical daily buoy coverage used in the match process. Weekly and monthly statistics for the entire globe (Fig. 1) and stratified latitude regions are generated from this dataset for regular accuracy and validation checks. Difference anomalies are routinely investigated for possible retrieval error and its relationship to other environmental parameters.

The NAVOCEANO WSC has developed a quality control and regional analysis support system to ensure the accuracy of the NAVOCEANO SST product. Quality control capabilities include several global and regional image graphics that allow for numerous parameter display options. An example quality control graphic is shown in Fig. 7. Retrievals that differ by more than 1°C from the 100-km SST field temperature can be quickly identified and investigated.

## 5. Future efforts

The NAVOCEANO WSC has recently rehosted its satellite SST processing software from antiquated mini-mainframes to a Unix workstation environment.

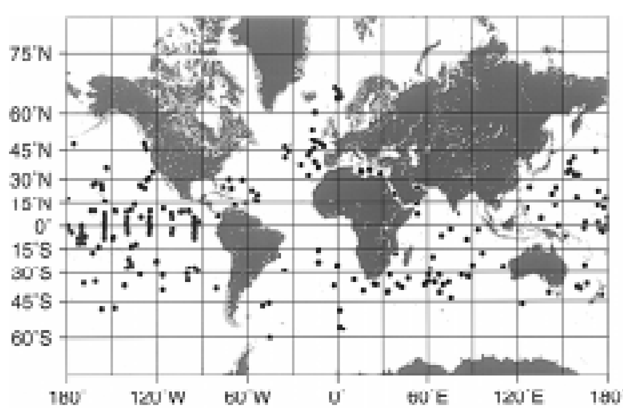


FIG. 6. Global buoy measurement locations received at NAVOCEANO for 28 January 1997.

In addition to transferring the satellite SST processing to more powerful and reliable platforms, the NAVOCEANO WSC is rewriting the satellite SST processing software under the direction of NRL and the ARP/SST. The NOAA and National Aeronautics and Space Administration Pathfinder program sea surface temperature scientists are also assisting the NAVOCEANO WSC, providing insight from their experience with high-resolution satellite SST processing. Other updates include improving the coastline database resolution and the analyzed temperature field resolution, which is used in the calculation of the NLSST and various cloud detection algorithms.

The NAVOCEANO WSC is preparing for SST processing from the next-generation AVHRR sensor data stream to be available from NOAA-K. The potential of operationally processing and distributing SST from multiple satellites as well as from NOAA/NESDIS Geostationary Operational Environmental Satellites will be evaluated. Another area being examined is skin SSTs versus bulk SSTs (Wick et al. 1992).

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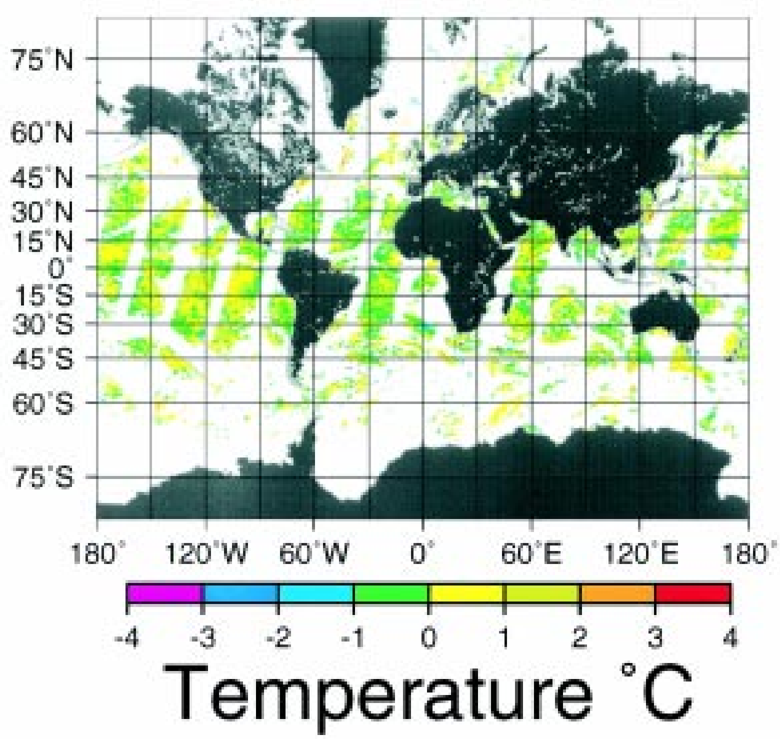


FIG. 7. Nighttime satellite SST retrieval value minus the 100-km analyzed field value for 29 January 1997.

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